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Agenda

- Risk vs Regret
- The Case Study – ORS AoA
  - Capabilities-Based Approach
  - ORS AoA Process
- Cost-Effectiveness – A Deeper Look
- Least Costly Launch Vehicle Architecture Alternatives
- Rank Order of Sensitivity Variability
- Average Regret Process & Results
- Minimax Regret Process & Results
- Summary
- Study Impact
- Conclusion

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Risk vs Regret

- **Risk**
  - Potential future harm that may arise from some present action
  - Often combined or confused with the probability of an event which is seen as undesirable
  - Some theorists have defined quite general methods to assess risk as an expected after-the-fact level of regret
    [http://www.wordiq.com/definition/Risk#Risk_as_regret]

- **Regret**
  - To experience regret on account of; to lose or miss with a sense of regret; to feel sorrow or dissatisfaction on account of (the happening or the loss of something); as, to regret an error; to regret lost opportunities or friends *[Source: Webster's Revised Unabridged Dictionary*

Regret

- **Regret associated with an outcome**
  - **Defined as the utility of that outcome subtracted from the maximum utility for a given condition**
  - **Measures the extent to which one would be unhappy to miss out on an outcome**
  - **Expresses how much worse things are than they would have been had one chosen the other option**
- **Calculate it by comparing the utility of the outcome with the maximum utility of that state (condition)**
  - **When the utility of an outcome is the maximum for that state (condition), the regret associated with that outcome is defined as zero**

http://www.utas.edu.au/docs/humsoc/philosophy/courses/reasoning/rs/overheads/o17f.htm

The Case Study Background

- AFSPC/DR was commissioned to deliver an Operationally Responsive Spacelift (ORS) Analysis of Alternatives (AoA) Study
- The Problem Statement was to determine the best means to *responsively*
  - Launch
  - Maneuver
  - Service
  - Retrieve

HOW TO

DO THIS

Space payloads

WITH THIS

To enhance military effectiveness

FOR THIS PURPOSE

Capabilities-Based Approach

TRADITIONAL APPROACH

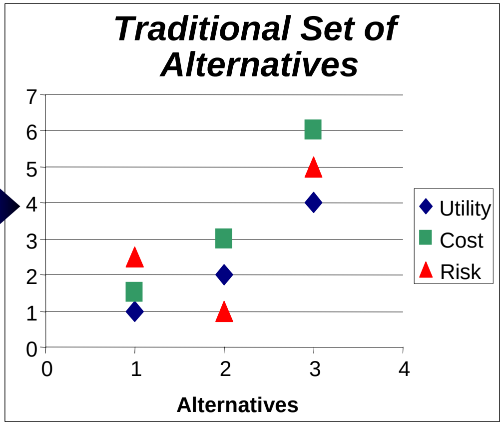
Alternative Selection and Design Process

Effectiveness Analysis

Cost Analysis

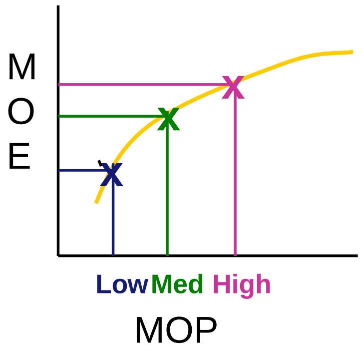
Risk Analysis

Other Analysis



ORS APPROACH

Effectiveness Analysis

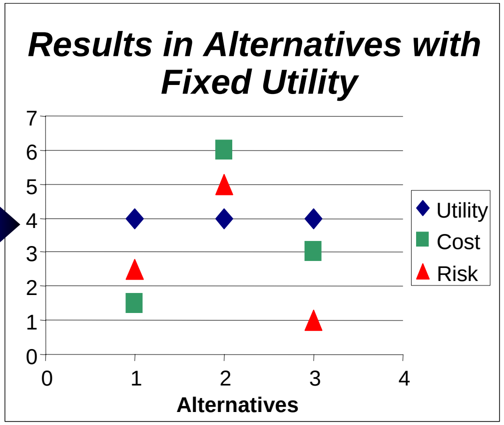


Alternative Design

Cost Analysis

Risk Analysis

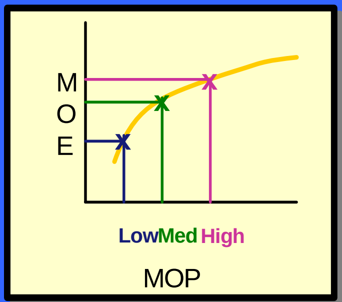
Other Analysis



ORS AoA Process: 4 Major Steps

1. **Examine Military Utility**
2. **Derive responsive space system architectures and launch loads**
3. **Explore responsive launch options to meet loads**
4. **Determine most cost- effective launch solution**

Military Utility Analysis



MOE= Measures of Effectiveness
MOP= Measures of Performance

Payload Capabilities (Surv, Recon, Nav)

Satellite Architectures (7 Identified)

Launch Demands to achieve L/M/H Utility

LV Options

LV Architectures (> 85 Identified)

CONOPS

Fleet Size, Facilities, Tech., Risk, & Cost to achieve L/M/H Utility

Cost Effectiveness & Risk Analysis

Results

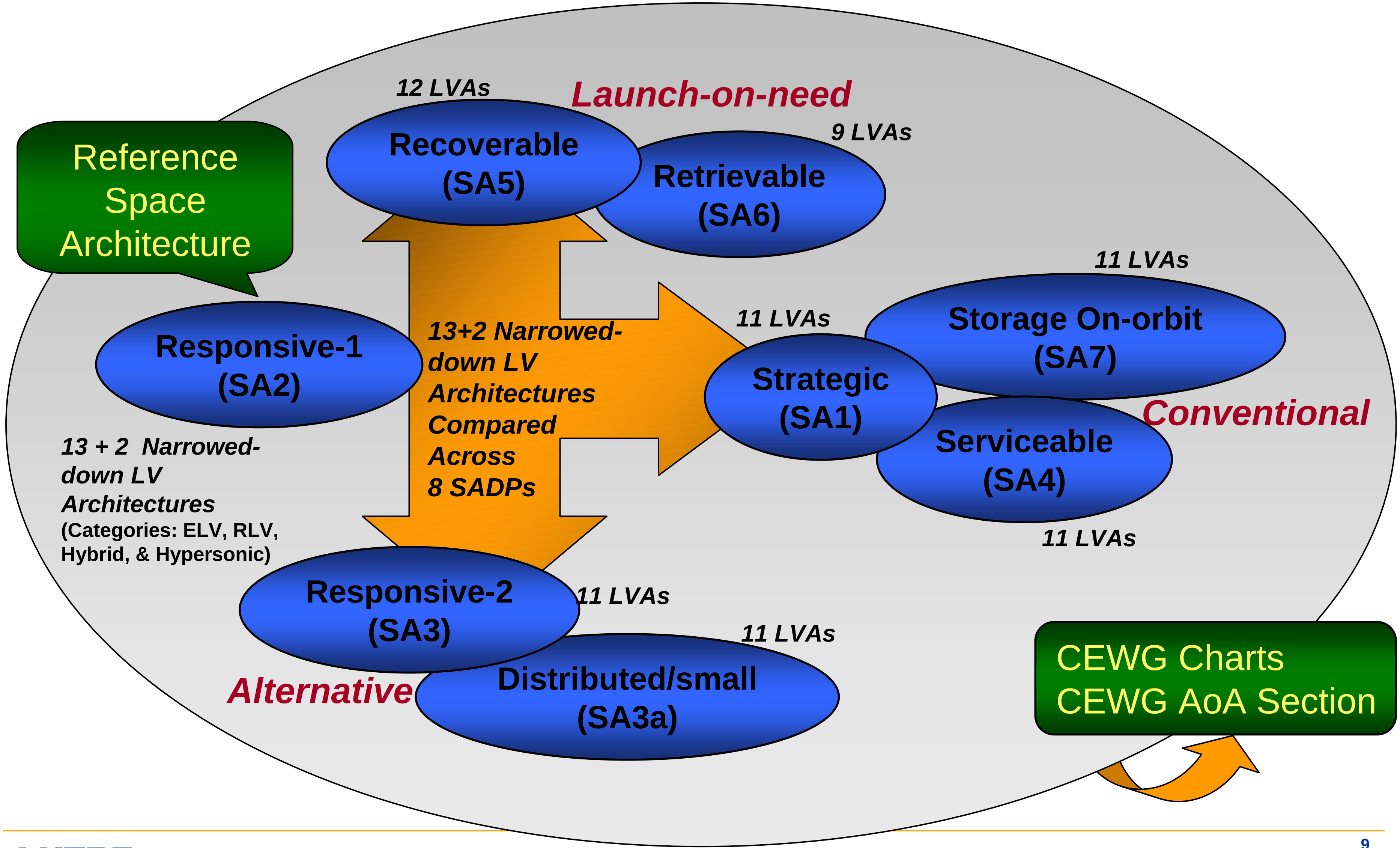
LV Concept	Utility	Cost	Risk
1	H	C1	R1
2	H	C2	R2
3	H	C3	R3
4	M	C4	R4
5	M	C5	R5
6	M	C6	R6
7	L	C7	R7
8	L	C8	R8
9	L	C9	R9

A Real Example – ORS AoA

- **Effectiveness Analysis Working Group**
  - Conducted a series of parametric experiments to establish three levels of performance (low, medium, and high)
  - Determined the military utility associated with those levels of performance
- **Integrated Concepts Working Group**
  - Used the parameters associated with L, M, H performance levels as the basis to develop alternatives
  - Involved establishing eight Space Asset Deployment Profiles (SADP) as alternative means to achieve the tasks required of the on-orbit assets
  - Devised a series of Spacelift Architecture Options to span the spectrum of potential approaches to responsive launch
- **Different launch capacities combined with these fundamental approaches, the set of Launch Vehicle Architectures (LVAs) > 85**
- **Reduced to 15 LVAs for detailed analysis, and costed for the SADPs**

Fixed performance across alternatives at a given performance level, enables the alternatives to be evaluated strictly on *cost* and *risk*.

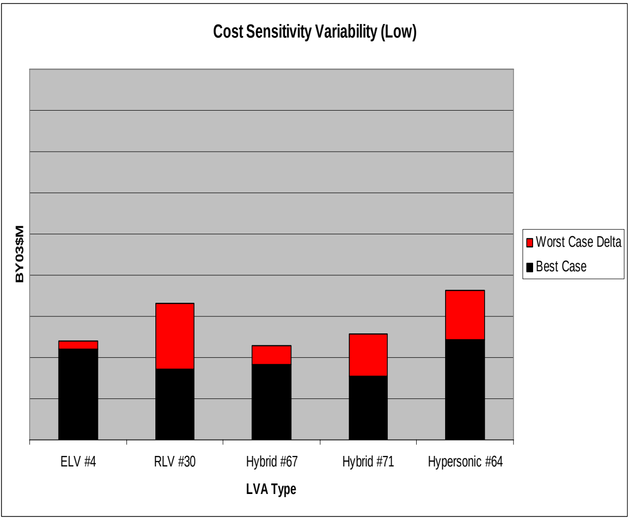
ORS AoA Space Asset Deployment Profiles

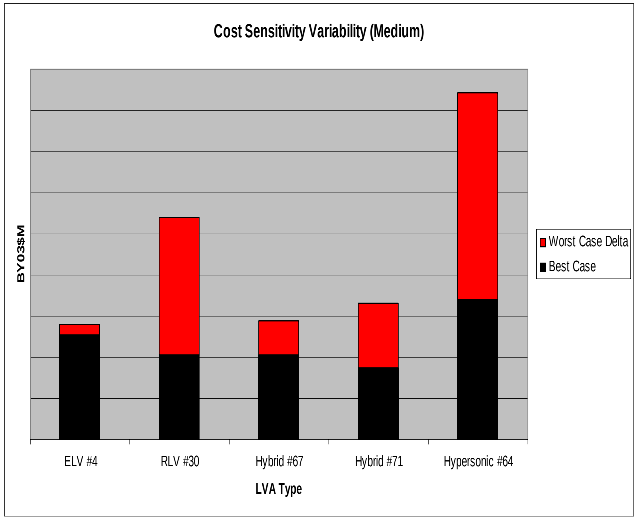


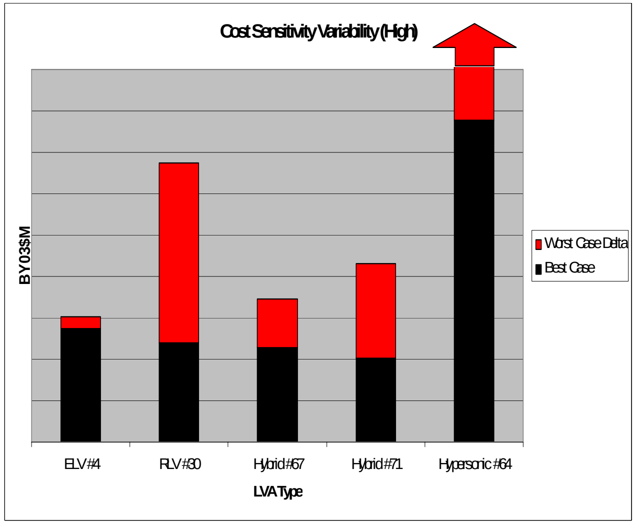
Cost-Effectiveness: A Deeper Look

The Cost Effectiveness Working Group faced two issues:

- **First issue: What is the relationship between performance and cost?**
  - **The LVA types were designed to achieve low, medium and high performance**







Best Case: the least expensive option is Hybrid LVA # 71

Worst Case: least expensive option is ELV or Hybrid LVA # 67

Best Case = Faster Processing, Low Prod Cost
Worst Case = Slower Processing, High Prod Cost

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Cost-Effectiveness: A Deeper Look

- **Second issue: What happens when you consider performance, cost, and risk together?**
  - The uncertainties in processing time and production cost are unknown - only extremes were analyzed
  - Undertook a variation of regret analysis to shed light on the question
- **“Regret” can be defined as “the difference in exposure between some choice and the best choice for a particular realization of the uncertainties”**
- **Average Regret**
  - Is the equivalent of having all equally likely outcomes
- **Minimax Regret**
  - Is equivalent to being pessimistic
  - The “Eeyore” syndrome

Least Costly Launch Vehicle Architecture Alternatives

- **There were 15 options in the set of narrowed-down LVAs spanning the four types of vehicles**
  - **3 Expendables, 8 Reusables, 3 Hybrids, 1 Hypersonic**
- **Included four conditions**
  - **High & Low Production Cost**
  - **Faster & Slower Processing**
- **Hybrid #71 has the lowest Life Cycle Cost Estimate for low performance…but that does not tell the whole story**

ORS AoA Launch Vehicle Architectures (LVAs)*

LVA #	Configuration		
	Vehicle A	Vehicle B	Vehicle C
Exp LVAs			
4	Sol 25 k	Exp-Generic EELV 45 k	
11	RPRP 25 k	Exp-Generic EELV 45 k	
12	RPRP 45 k		
Reuseable LVAs			
30	RPOpt 15 k	RPOpt Growth to Trimese	
36	RPLHOpt 5 k	RPLHOpt Growth to 45 k	
39	RPLHOpt 25 k	Exp-Generic EELV 45 k	
41	RPLHOpt 45 k		
46	LH Bimese 15 k	LHBi Growth to 45 k	
47	LH Bimese 15 k	LHBi Growth to Trimese	
48	LH Bimese 25 k	Exp-Generic EELV 45 k	
51	LH Bimese 45 k		
Hypersonic LVAs			
64	RBCC 25 k	Exp-Generic EELV 45 k	
Hybrid LVAs			
67	RLV/ELV-Solid RD180	Exp-Generic EELV 25 k	Exp-Generic EELV 45 k
70	RLV/ELV 12.7k	Hybrid 2 RLVs/ELV 45k	
71	RLV/ELV 19.5k	Hybrid Growth to Trimese	

***This presentation will not discuss the details of the LVs**

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Rank Order of Sensitivity Variability

Space Architecture	Arch 2	Arch 2	Arch 2	Arch 2	Arch 2	Arch 2	Arch 2	Arch 2	Arch 2	Arch 2	Arch 2	Arch 2
Performance	Low	Low	Low	Low	Medium	Medium	Medium	Medium	High	High	High	High
Processing Time	Faster	Faster	Slower	Slower	Faster	Faster	Slower	Slower	Faster	Faster	Slower	Slower
Production Cost	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Expendable (4)	6	12	2	9	4	11	1	4	4	10	1	2
Expendable (11)	8	13	3	10	5	13	2	5	5	12	3	6
Expendable (12)	13	15	6	12	8	14	4	6	6	13	2	5
Reusable (30)	5	2	11	8	6	4	8	8	7	5	10	11
Reusable (36)	11	10	10	11	12	10	9	9	11	8	7	7
Reusable (39)	4	7	7	5	9	9	11	12	12	11	12	12
Reusable (41)	7	3	8	4	7	5	7	7	8	6	9	9
Reusable (46)	12	8	14	13	10	7	10	10	10	7	11	10
Reusable (47)	14	9	15	14	11	6	12	11	9	4	8	8
Reusable (48)	10	11	9	7	14	12	13	14	14	14	13	14
Reusable (51)	9	4	12	6	13	8	14	13	13	9	14	13
Hypersonic (64)	15	14	13	15	15	15	15	15	15	15	15	15
Hybrid (67)	2	6	1	2	2	3	3	2	1	3	4	1
Hybrid (70)	3	5	5	3	3	2	5	3	3	2	5	3
Hybrid (71)	1	1	4	1	1	1	6	1	2	1	6	4

What's going on between #71 & #67?

- **For Low production cost, 5 of 6 times #71 wins (Red oval)**
- **For High production cost, 2 of 6 times #71 wins (Black oval)**
- **For Faster processing time, #71 ranks first 5 of 6 times.**
- **For Slower processing time, #71 ranks first 2 of 6 times.**

Are *Low* production cost and *Faster* processing time really possible?

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Process to Calculate Average Regret

1. **Compare Cost of each LVA to Hybrid LVA #71 to identify a delta**
   - If delta is positive, LVA #71 cheaper
   - If delta cost is negative, LVA #71 is more expensive
2. **Calculate the four deltas at each performance level for the four conditions:**
   - Low Prod Cost, Faster Processing Time
   - High Prod Cost, Faster Processing Time
   - Low Prod Cost, Slower Processing Time
   - High Prod Cost, Slower Processing Time
3. **Sum delta costs (step 2) across the four conditions**
4. **Calculate average regret value (step 3 divided by 4)**
   - If average delta is positive, LVA #71 is cheaper

- **Issues/Concerns**
  - Each condition does not have the same probability

ORS AoA Average Regret

(All vs Hybrid LVA #71)

- **Positive regret values reflect average potential savings (BY03$M) by choosing Hybrid LVA #71 concept over other LVA concepts**
- **Negative regret value reflect average potential costs by choosing Hybrid LVA #71 concept over that LVA concept**

Architecture	SA 2	SA 2	SA 2
Performance	Low	Medium	High
Average Regret versus LVA #71	(+ is good for LVA #71)		
Expendable (4)	15,596	11,727	-6,034
Expendable (11)	19,592	18,455	4,764
Expendable (12)	29,776	27,023	4,299
Reusable (30)	20,235	50,253	58,743
Reusable (36)	28,342	62,334	54,426
Reusable (39)	14,241	66,073	89,367
Reusable (41)	16,110	47,311	54,096
Reusable (46)	40,830	62,298	62,382
Reusable (47)	45,611	64,472	52,762
Reusable (48)	24,554	87,401	108,274
Reusable (51)	23,207	86,647	98,980
Hypersonic (64)	48,274	153,307	228,433
Hybrid (67)	2,174	-496	-10,688
Hybrid (70)	8,150	5,974	-1,435

Minimax Regret Analysis

- **Decisions made with minimizing the maximum regret are to control the remorse that inevitably accompanies hindsight**
- **Minimax Regret is distribution independent which gives it its power (not uniformly distributed)**
- **All other LVAs were compared to the least costly LVA in each case within each performance level. This regret function is:**

    Minimax Regret (of a particular alternative #) = (LCCE of other LVA #) – (Least costly LCCE)

ORS AoA Minimax Regret Process & Results

1. **Find lowest LCCE for each condition**
2. **Calculate regret value by subtracting the lowest LCCE (step 1) from each of the other LVAs within the respective condition**
3. **Obtain maximum regret value for each LVA by taking the largest regret value of the four conditions**
4. **Choose the minimum of the maximum regret values for each performance level**
5. **Examine the first and second choices for inconsistencies**

(Due to complexity of this process, steps will be shown in detail)

	Space Arch 2		
	Low	Med	High
Max Regret (BY03$M)			
Expendable (4)	33,563	39,004	35,574
Expendable (11)	39,881	47,482	47,305
Expendable (12)	49,943	56,713	48,609
Reusable (30)	51,055	130,510	185,371
Reusable (36)	50,236	133,708	155,299
Reusable (39)	29,269	146,831	233,414
Reusable (41)	36,083	116,009	172,178
Reusable (46)	86,072	145,051	187,384
Reusable (47)	95,956	150,581	171,974
Reusable (48)	38,535	178,474	257,857
Reusable (51)	51,900	200,298	267,315
Hypersonic (64)	66,475	281,238	478,988
Hybrid (67)	14,138	14,777	21,107
Hybrid (70)	14,666	23,869	47,700
Hybrid (71)	13,748	26,226	64,576
Mini-Max Regret			
	Hybrid (71)	Hybrid (67)	Hybrid (67)
	13,748	14,777	21,107
Delta between 71 & 67:	-390	11,449	43,468

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ORS AoA Minimax Regret Process & Results

1. Find lowest LCCE for each condition
2. **Calculate regret value by subtracting the lowest LCCE (step 1) from each of the other LVAs within the respective condition**
3. Obtain maximum regret value for each LVA by taking the largest regret value of the four conditions
4. Choose the minimum of the maximum regret values for each performance level
5. Examine the first and second choices for inconsistencies

Architecture	SA 2	SA 2	SA 2	SA 2
Performance	Low	Low	Low	Low
Processing time	Faster	Faster	Slower	Slower
Production Cost	High	Low	High	Low
Expendable (4)	20,679	**33,563**	5,141	16,747
Expendable (11)	26,996	**39,881**	6,817	18,423
Expendable (12)	37,058	**49,943**	17,122	28,728
Reusable (30)	17,876	9,278	**51,055**	16,479
Reusable (36)	34,538	22,463	**50,236**	19,879
Reusable (39)	16,488	14,815	**29,269**	10,140
Reusable (41)	21,165	12,022	**36,083**	8,920
Reusable (46)	36,394	19,843	**86,072**	34,759
Reusable (47)	39,855	20,681	**95,956**	39,699
Reusable (48)	33,320	24,394	**38,535**	15,716
Reusable (51)	27,823	12,678	**51,900**	14,174
Hypersonic (64)	55,760	44,796	**66,475**	39,813
Hybrid (67)	5,352	**14,138**	0	2,952
Hybrid (70)	10,183	13,502	**14,666**	7,996
Hybrid (71)	0	0	**13,748**	0

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ORS AoA Minimax Regret Process & Results

1. Find lowest LCCE for each condition
2. Calculate regret value by subtracting the lowest LCCE (step 1) from each of the other LVAs within the respective condition
3. **Obtain maximum regret value for each LVA by taking the largest regret value of the four conditions**
4. Choose the minimum of the maximum regret values for each performance level
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Architecture	SA 2
Performance	Low
Expendable (4)	33,563
Expendable (11)	39,881
Expendable (12)	49,943
Reusable (30)	51,055
Reusable (36)	50,236
Reusable (39)	29,269
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Reusable (51)	51,900
Hypersonic (64)	66,475
Hybrid (67)	14,138
Hybrid (70)	14,666
Hybrid (71)	13,748

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ORS AoA Minimax Regret Process & Results

1. Find lowest LCCE for each condition
2. Calculate regret value by subtracting the lowest LCCE (step 1) from each of the other LVAs within the respective condition
3. Obtain maximum regret value for each LVA by taking the largest regret value of the four conditions
4. **Choose the minimum of the maximum regret values for each performance level**
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Mini-Max Regret			
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	13,748	14,777	21,107
Delta between 71 & 67:	-390	11,449	43,468

Comparison of Average vs Minimax Regret

- **Average Regret**
  - **Hides results for the conditions where hybrid does not win**
  - **Do not have insight into the combination of conditions (cost and processing time) for which LVA #71 is better than LVA #67**
  - **Do not know which conditions directly affected the LCCEs of LVA #67 and LVA #71**
- **Minimax Regret**
  - **Revealed the hybrid type launch vehicle had the least regret for all performance levels**
  - **Through minimax regret analysis, the decision-maker can see which hybrid launch vehicle to pursue if growth in performance (low, medium, or high), funding, or risk were priorities**

Average Regret & Minimax Regret can be powerful analytical tools if *limitations* of each are known and understood

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Summary (cont.)

- **Clearly there is an interaction between the performance levels and which hybrid is best**
- **Regret analysis verifies that hybrid LVA does beat the other LVA types – even when we assume the worst condition**
- **Regret analysis gave AFSPC and other decision-makers repeatable, traceable analysis to focus on the most viable architecture type**
- **ORS AoA recommended to pursue first stage reusable launch vehicle (RLV) demonstrations**
  - **Assess cost, operability, technology readiness levels**
  - **Test operations concepts/processes**
  - **Follow-on demonstrations of Hybrid (reusable first stage with expendable upper stages)**
  - **Assess scalability of cost and operations data; test more realistic operations concepts**

Demonstrations will reduce *cost uncertainty* as well as *technical risk*

Study Impact

- Since completion of this study, the HQ AFSPC/CC gave permission in January 2005 for the ORS Demonstrator to begin
- A Phase I Program Research and Development Announcement (PRDA) notice was posted on February 16, 2005 for the Affordable REsponsive Spacelift-Subscale Demonstration (ARES-SD)
- The ARES Phase I Concept Development and Demonstration Planning Program is contracted by the Department of the Air Force, Air Force Space Command, SMC - Space and Missiles System Center

Conclusion

- **Bottom line: different tools and types of analysis yield different analysis results**
- **To achieve unbiased analysis, the analyst cannot overlook one tool or type of analysis over another**
- **When used appropriately, Average Regret and Minimax Regret can be powerful analytical tools if limitations of each are known and understood**